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OVERVIEW OF LEWIS MATERIALS RESEARCH - CONTRIBUTIONS, CURRENT EFFORTS, AND FUTURE DIRECTIONS

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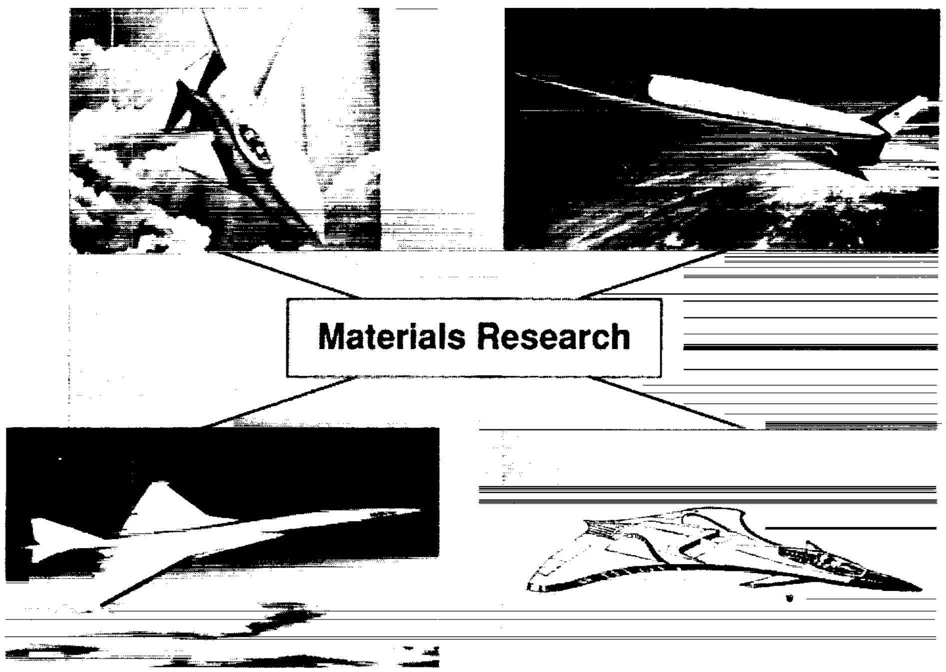
In the 1940's, materials research efforts on high-temperature valve alloys at NASA Lewis Research Center led to the improved lives and performance of piston-engined fighter and bomber aircraft. The metallurgical skills acquired from that work were then applied to the formulation of high-temperature turbine blade alloys for aircraft gas turbine engines developed in the 1950's. Today, the benefits of superior U.S. engine technology have never been clearer for both commercial and military aircraft. Yet, these superior engines of the 1980's and 1990's now use some of the materials that we helped conceive and evolve in the 1960's and 1970's. NASA Lewis is currently charged with helping industry create, advance, and develop the materials for 21st century engines - 2005 to 2015+. In this paper, we present highlights of our past work, our staff, and our facilities. We also summarize the challenges and new material and process concepts we are working on now as well as our vision for future efforts.

Advanced Systems Won't Fly Without Advanced Materials



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From advanced hypersonic aircraft to supersonic fighters and commercial transports, tomorrow's aircraft will stretch the limits of materials technology. Both airframe and engine materials and structures will require extended temperature capability in conjunction with the same or longer life compared with today's systems. Practical advanced engines require hot, highly loaded rotating and static components which must resist very aggressive oxidation-corrosion environments. Temperatures are rising, lives must be long, and weight must be reduced.

Thus we face many tough challenges as we pursue the advanced revolutionary technologies that offer the potential solutions to our problems: that is, high-temperature composites. Furthermore, instead of the 15 to 20 years that it has usually taken for materials to develop from concept to commercialization, we now are being asked to deliver these materials in only 10 to 12 years. Thus, the requirements are great, and only a very strong collaborative effort between the Government, industry, and academia will let us reach our goals.

We're a Major Government Aerospace Materials Laboratory

- Continued output of technology that is used by industry
  - PMR polymer composites
  - Thermal barrier coatings
  - MCrAl's
  - Ceramic composites
  - Solid, high-temperature lubes
  - Metal matrix composites
- High-quality staff
- Strong in-house capability
- Solid, collaborative ties to industry and key universities

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Lewis Research Center's Materials Division is NASA's major high-temperature materials research group. It has a long history of technical contributions that have been used by the aerospace industry. Such contributions are the result of considerable efforts to recruit and retain top researchers, to provide facilities and laboratories that effectively support them, and to interact well with industry and universities to facilitate the exchange of new developments.

Our Job

- New materials, insights into technical challenges, and process models for the next generation of NASA and aerospace industry needs
- Technology acceleration via cooperative, collaborative research with industry
- "Generic component" materials and process technology options and rapid technology transfer to support conversion of ideas into U.S. competitive systems
- Direct support of major NASA flight projects

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Our Technology is Used by Industry, and We Work on Barrier Problems

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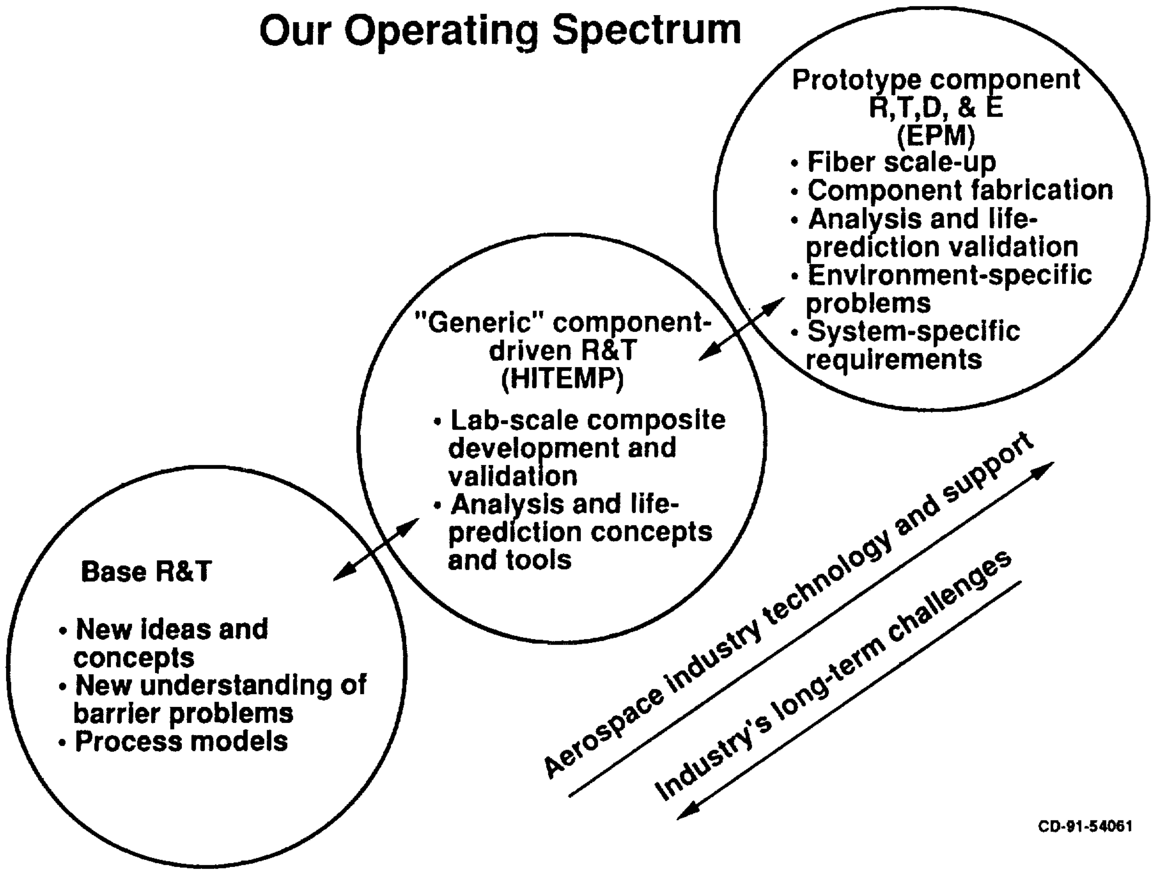
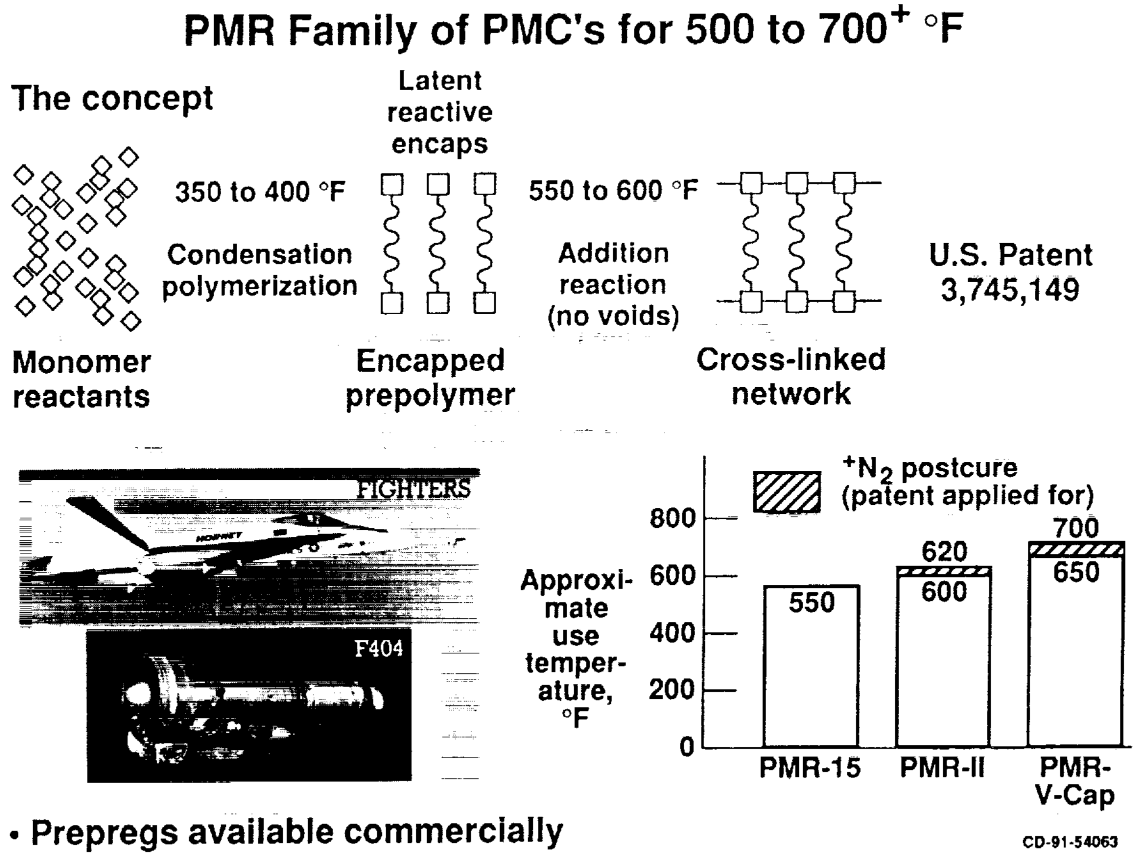


New ideas generated by our base research and technology which meet generic component needs receive focused development and evaluation efforts. Promising materials systems are further optimized, scaled-up, and transitioned into prototype components for detailed industry assessment. From such work, new long-term barrier problems are identified and act as a guide for new base research and technology efforts.



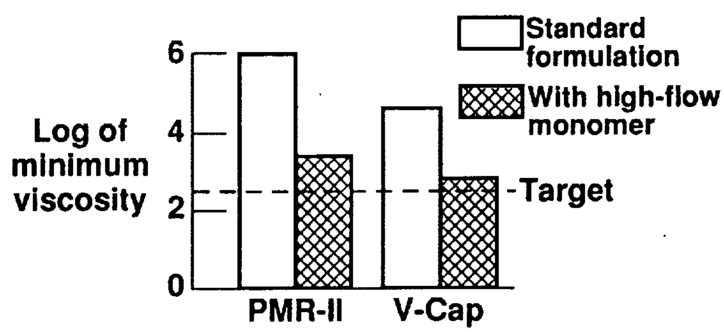
In the late 1960's and early 1970's, Lewis researchers developed a new concept, a two-step polymerization of monomeric reactants (PMR) process to make polyimide composites. This process allowed liquid and gas reaction products to escape the composite structure prior to final cross-linking. As a result, fewer voids were retained, and processing became more flexible for high-temperature polyimide resins. Such resins are usually intractable. Through collaboration with the U.S. Navy and General Electric Company, PMR-15 engine ducts are flying in the F404 engines that power the Navy's F-18 Hornet fighters. These ducts save about 30 percent of the total weight and cost of the previously used, chemically-milled titanium ducts. Recent advances by Lewis scientists have increased polymer molecular weight, have added more thermally stable end-caps, and have, by a nitrogen post cure, substantially raised the glass transition temperature. These advances, in turn, allow higher ultimate use temperatures. Prepregs of PMR-15, PMR-II (increased molecular weight), and PMR-VCP (vinyl end-cap) are now available commercially.

Polymer Composites - Current Efforts for Future Options

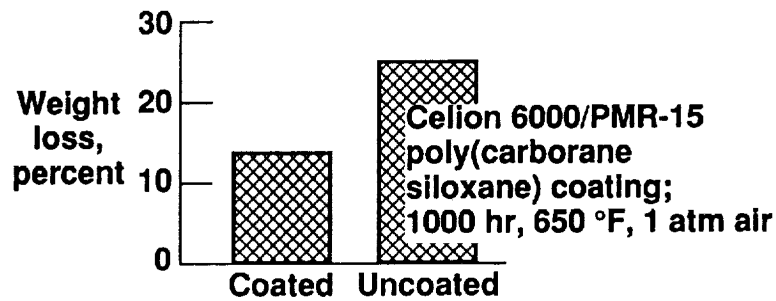
Challenges | **Progress**

- Higher flow resins to ↑ fabricability (and ↓ cost)

Improved resin flow and processability



- Chemistry and surface control to ↑ oxidation resistance



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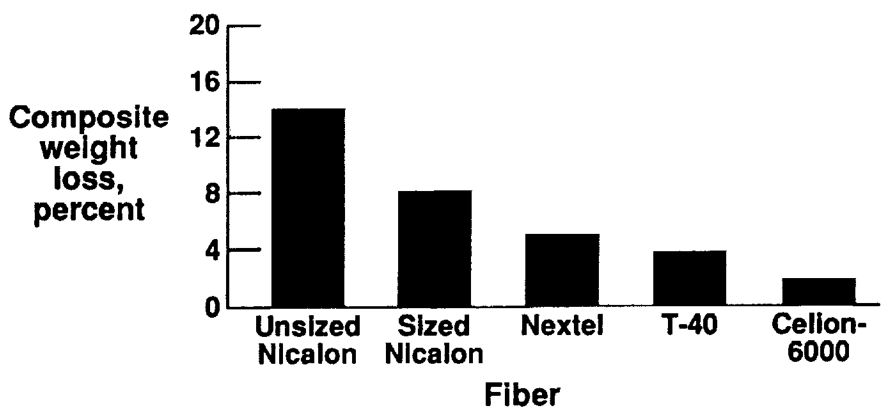
- Fiber/matrix interface control to ↑ long-term properties

Composite weight loss



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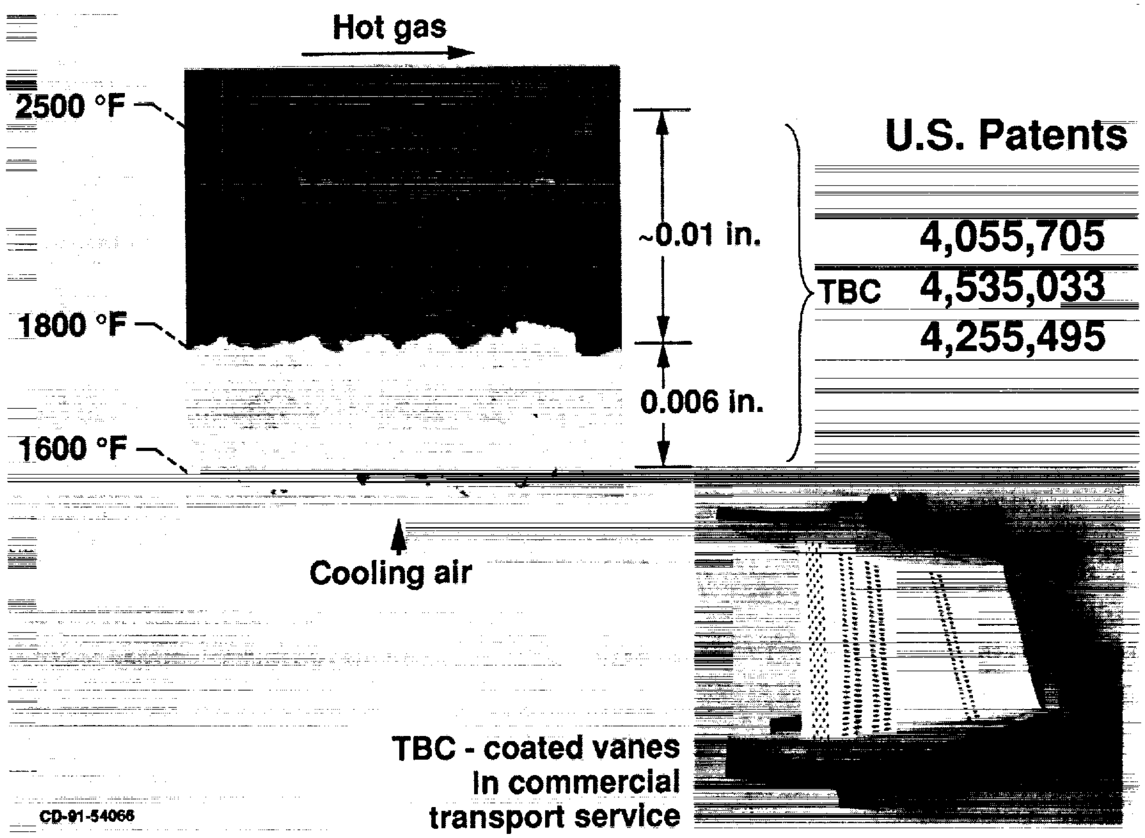
The major challenges we are facing include cost reduction and extended oxidation and environmental resistance. To reduce fabrication costs, we are using high-flow monomers to lower resin viscosity and make it easier to produce polymer matrix composites (PMC's) at lower temperatures or reduced autoclave pressures. To improve oxidation resistance, we are exploring a number of organic and inorganic surface coatings as well as trying to understand and control fiber/matrix reactions to preclude rapid oxidation attack along these interfaces.

Thermal Barrier Coatings (TBC)



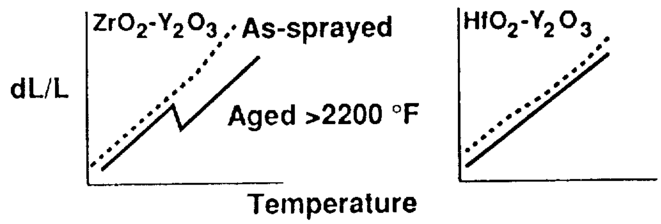
Thermal barrier coatings offer a way to operate air-cooled superalloy vanes, blades, and other aircraft components in high heat flux environments while maintaining reasonable substrate temperatures. The early Lewis Research Center work identified the plasma-sprayed two-layer coating (ZrO_2-$6Y_2O_3$ to ZrO_2-$8Y_2O_3$) partially stabilized zirconia outer coat deposited on a NiCrAlY oxidation-resistant bond coat layer. This coating has been embraced by industry, and components protected by variations on it are flying in many aircraft engines.

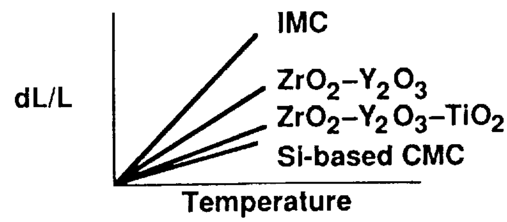
Thermal Barrier Coatings-
Current Efforts for Future Options

Challenges

- Resistance to higher surface and bond coat temperatures
- Useful life on either high or low C.T.E. substrates
- Reliable performance

Progress





Process control for
- Reproducibility
- Productivity
- Quality
- Safety

Allows
- Meaningful optimization

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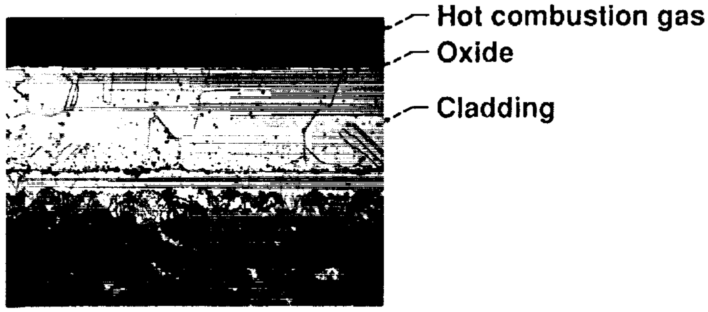
The challenges for more extensive thermal barrier coatings (TBC) use include higher temperature resistance, ability to resist spalling, and general reproducibility of performance. We have been studying stabilized HfO_2 systems which appear to be more resistant to eventual destabilization of the oxide and the resultant expansion inversion that occurs during temperature cycling.

Further alloying of the oxides provides one way to modify CTE's for greater spall resistance. To develop more reproducible systems, we are currently evaluating robot-controlled, rather than hand-held, plasma spray systems.

MCrAl's as Protection Systems



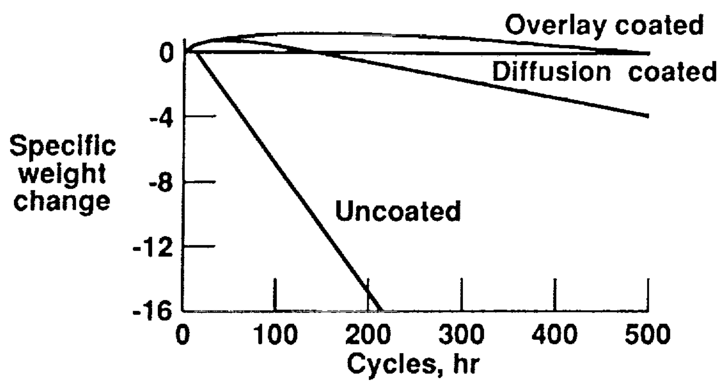
U.S. Patents

4,451,496
4,446,199
3,869,779

Cyclic oxidation mechanisms

Cladding (BMI) and testing

Most engines



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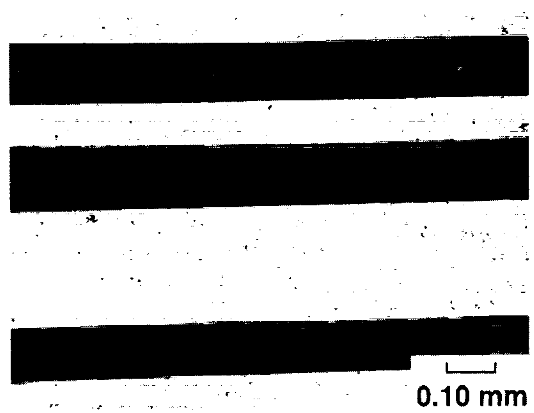
We previously discussed the two-layer TBC system. The success of such coatings can be, in part, traced to earlier Lewis work on cyclic oxidation fundamentals of a variety of nickel and iron alloys. We found a clear and overwhelming benefit of reasonably high combined Cr and Al levels in such alloys on their ability to form thin, adherent alumina scales which rapidly reformed if they spalled. This led to the study of Cr/Al balance; the study of cycle temperature, hold time, cooling time, and other effects; and attempts to apply promising alloys as clads via HIP processing (the latter work was done contractually for Lewis by Battelle Memorial Institute). The performance of such clad superalloys - their long-term cyclic oxidation protection - helped motivate the industry to use current physical vapor deposition (PVD) overlay coatings for airfoils.

NiCrAl's - Current
Efforts for Future Options

Challenges

- Reinforce weak, but oxidation resistant, material for structural use

Progress



Al_2O_3/FeCrAlY

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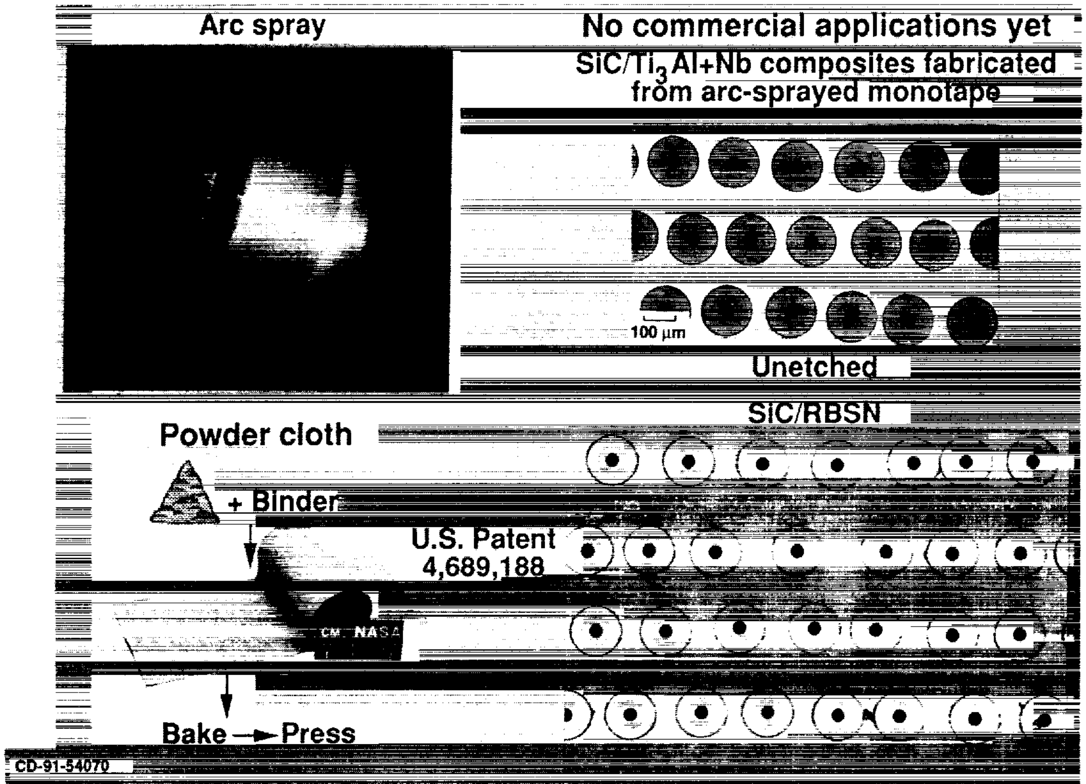
As an alternative option, we are attempting to eliminate the substrate entirely and reinforce the weak, but highly oxidation resistant, former coating and cladding alloys. This concept offers some interesting potential, and early tests show good resistance to thermal cycling.

Composite Fabrication



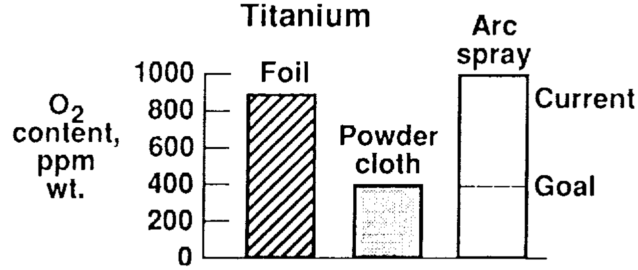
Numerous advanced fabrication processes have been developed in the Materials Division. The Lewis-patented arc spray method and the "powder cloth" approach have been used to make intermetallic and ceramic monotapes. Such tapes can then be angle plied, laid up, and hot pressed or HIPed to the final desired density and near-net shape.

Composite Fabrication-
Current Efforts for Future Options

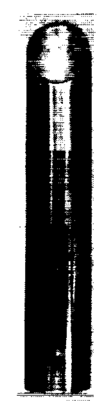
Challenges

- Minimal process contamination

Progress



- Complex shapes to near-net shape



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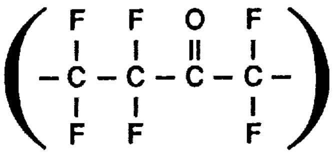
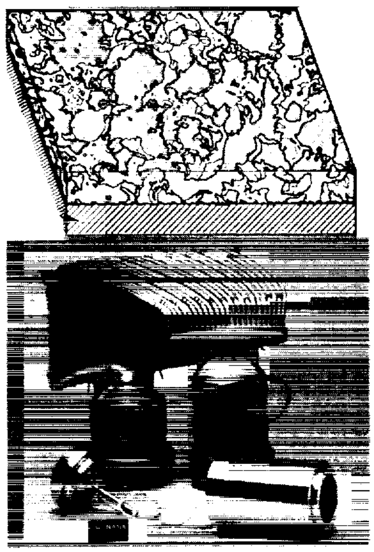
Monotapes offer a low-cost approach to composite fabrication, and arc-sprayed monotapes offer an even lower total cost. Our efforts to minimize material contamination during monotape fabrication have been progressing well. Titanium composites have been made with less than half the oxygen content of composites made by the foil-rolling approach. The lower cost, arc-sprayed titanium composites are equal in oxygen to those made by the foil process, but we have ideas that we think will let us reach an oxygen level near that of powder-cloth composites.

Fabrication to near-net shape is critical in minimizing composite component costs. Early efforts to fabricate metal matrix composite blades (NASA contract with TRW) and tubing (Lewis) provided us new insights into such processes.

Trying to Meet Severe Lubrication Requirements

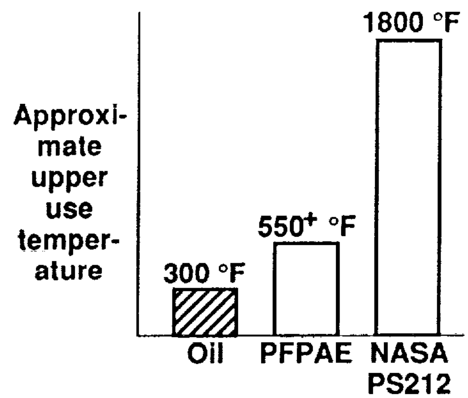


Perfluoro-polyalkyl-ethers



PS-212

U.S. Patent 4,728,448



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Aircraft engines that require ever-higher operating temperatures also require liquid lubricants that function well under increased temperatures. Such higher temperature lubricants also minimize total engine weight because of their reduced need for auxiliary oil coolers. These lubricants may also better resist lubricant decomposition during service. Our work focuses on understanding the stability of candidate perfluoropolyalkylethers (PFPAE) and exploring ways to increase their stability. In addition, we are also looking for solid lubricants for advanced gas turbines, Stirling engines, and internal combustion engines that can operate at much higher temperatures. NASA has developed a solid lubricant family called PS/PM200 that has an operating potential to 1800+ °F.

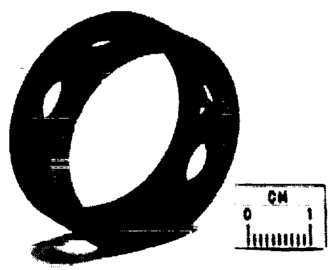
High-Temperature Lubricants-
Current Efforts for Future Options

Challenges

- High-temperature strength, oxidation, and reactions

Progress

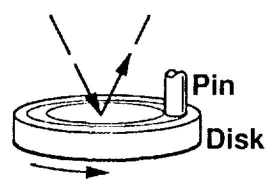
PM-200



Strength at room temperature ≅ bronze

Strength at high temperature ≅ stainless steel

ESCA



Surface oxide catalyzed PFPAE lubricant decomposition

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Since high-temperature lubricant properties such as strength (for solid lubes), oxidation resistance, and reactivity are barriers to even hotter bearings, we are focusing on these problems. Currently, a powder metallurgy (PM) version of our plasma-sprayed (PS) solid lubricant is showing promise with strengths equal to many of the current bearing materials. Our work on liquid lubricants is currently focused on basic understanding of reaction mechanisms, as well as on minimizing the catalytic decomposition of PFPAE caused by surface films on metals.

Advanced Degrees of Materials Division Staff

	Ph.D.	M.S.
• Materials	31	24
— Materials Science	(13)	(1)
— Metallurgy	(14)	(15)
— Ceramics	(4)	(8)
• Chemistry and chemical engineering	17	5
• Physics	11	4
• Mechanical engineering	5	4
• Other	10	6
Totals	74	43
Total staff * = 196		

* 3/4 of staff hired since 1980 — A young, aggressive staff

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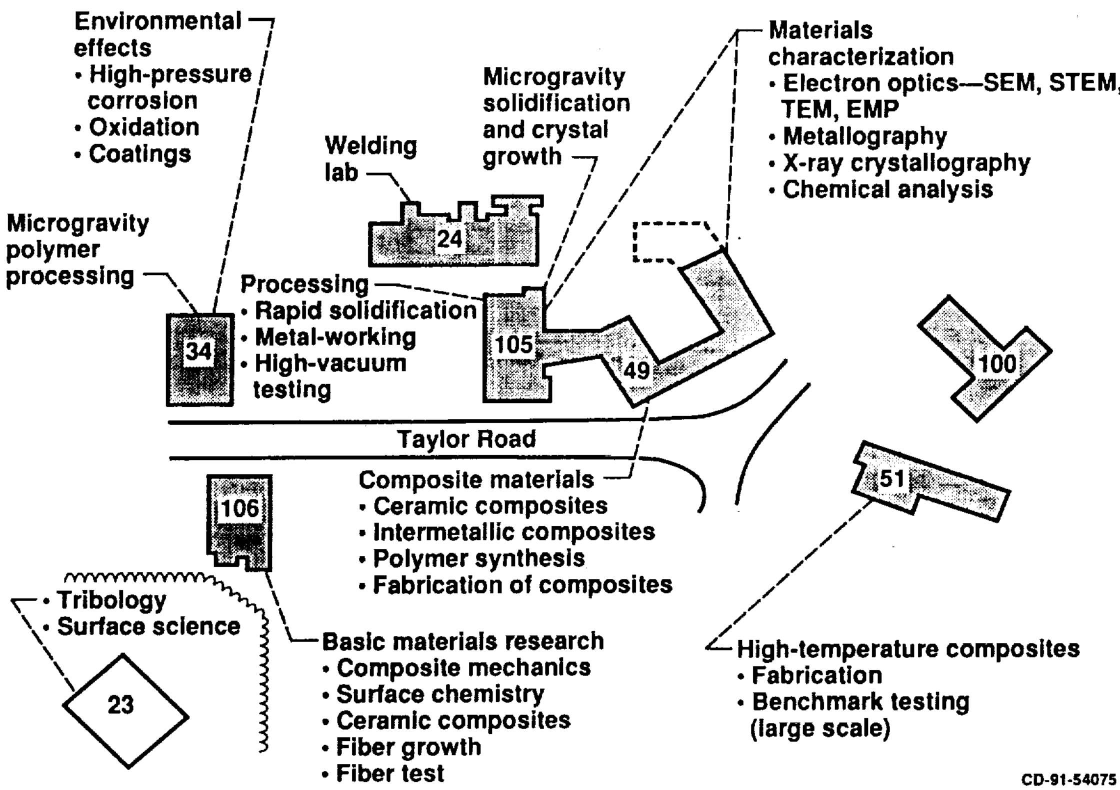
We have a high quality, young staff with a broad range of backgrounds and skills. Currently, of 196 total staff, 74 hold Ph.D.'s and 43 have M.S.'s. Although, as expected, our heaviest concentration of expertise is in the materials area, our staff is well balanced with top chemists, physicists, mechanical engineers, computer scientists, and aeronautical engineers. Note that approximately 75 percent of our staff has been hired within the last 10+ years, so our skills are very much up-to-date.

Lewis Materials Research Areas



We have a large, comprehensive materials research complex. We can fabricate, melt, cast, extrude, roll, weld, machine, test, and characterize all the systems we are investigating. These facilities plus our excellent staff offer industry and academic scientists and engineers a wide range of opportunities for research collaboration on problems of mutual interest.

Our Vision of the Future

- Continuing major R&T contributions - ideas and understanding

- PMC - IMC - MMC	- CMC - Fibers and coatings - Lubricants	Raise use-temperatures, extend life, lower fabrication cost

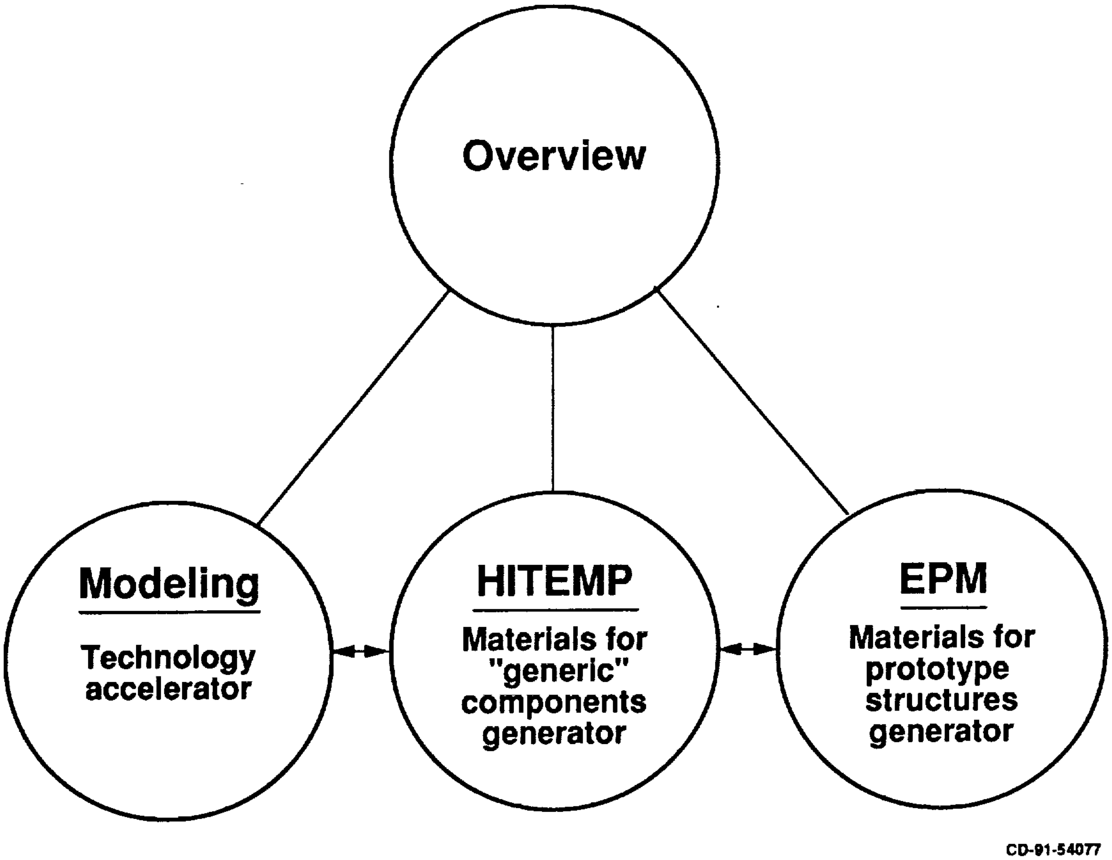
- More rapid movement of U.S. ideas to commercial and flight use
  - Process modeling to guide process optimization
  - Very close industrial collaboration on key opportunities – HITEMP, EPM, base R&T

- A growing national resource for high-temperature materials collaboration (call S. Grisaffe (216)-433-3193)

CD-91-54076

In the future, we will continue work to extend the use temperatures and operating lives of advanced composite engine materials while seeking new processes and process models with the potential to shorten time-to-process optimization and help lower costs.

We are dedicated to collaborating with industry, universities, and other agencies so that new ideas move rapidly into commercial and military systems. We are also dedicated to improving the competitive advantage of U.S. aerospace industries and the U.S. preeminence in world markets.



We will now describe several specific projects aimed at generating and accelerating technology flow to U.S. industry. In our process modeling effort, we are working to assure a sound understanding of key interactive process variables and then to reduce the time to optimize processes. This is a key factor that can reduce the time from material and process concept to commercialization. Our other modeling efforts focus on microstructure versus property relationships in complex alloys and composites.

Our HITEMP (Advanced High-Temperature Engine Materials) program is aimed at rapidly verifying the promise of new materials, processes, and analytical methods at the laboratory specimen level. Its focus is on materials with potential for "generic" classes of components - with emphasis on key property ranges and performance characteristics (e.g., compressor blades, disks, combustors, cases, turbine vanes, turbine blades, and other components).

EPM (Enabling Propulsion Materials) is a very focused program aimed at providing and scaling up the critical, long-lead-time materials for a U.S. high-speed civil transport engine. These materials include ceramic matrix composites for low NO_x combustors and intermetallic matrix composites for lightweight exhaust nozzles.

CONCLUSIONS

1. We have a solid "track record" of working with industry to accelerate the introduction of new technology into engines.

2. We have a strong staff and a clear vision of future engine needs.

3. We have a strong commitment to collaborate with industry to help keep the United States preeminent in aircraft gas turbine engine technology.